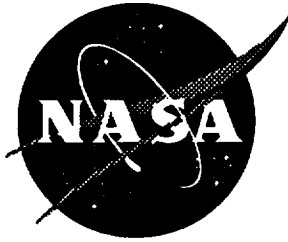


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Flight Test Maneuvers for Closed Loop Lateral-Directional Modeling of the F-18 High Alpha Research Vehicle (HARV) Using Forebody Strakes

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Abstract

Flight test maneuvers are specified for the F-18 High Alpha Research Vehicle (HARV). The maneuvers were designed for closed loop parameter identification purposes, specifically for lateral linear model parameter estimation at 30, 45, and 60 degrees angle of attack, using the Actuated Nose Strakes for Enhanced Rolling (ANSER) control law in Strake (S) mode and Strake / Thrust Vectoring (STV) mode. Each maneuver is to be realized by applying square wave inputs to specific pilot station controls using the On-Board Excitation System (OBES). Maneuver descriptions and complete specifications of the time / amplitude points defining each input are included, along with plots of the input time histories.

Nomenclature

ANSER Actuated Nose Strakes for Enhanced Rolling

h altitude, feet

OBES On-Board Excitation System

S strake

STV strake / thrust vectoring

t time, seconds

V airspeed, feet/second

α angle of attack, degrees

η_a lateral stick deflection in inches, positive for right stick

η_r rudder pedal force in pounds, positive for right rudder

subscripts

o nominal or trim value

I. Introduction

The F-18 High Alpha Research Vehicle (HARV) is a highly instrumented research aircraft used in the NASA High Alpha Technology Program¹. Objectives for this program include validating advanced control system design techniques in flight.

In this work, the technique described in references [2] and [3] was used to design flight test maneuvers consisting of optimal closed loop square wave inputs. These square wave inputs are to be applied directly to pilot station controls by the On-Board Excitation System (OBES)⁴. The optimal input design technique uses dynamic programming to compute globally optimal square wave inputs for model parameter estimation experiments, based on *a priori* dynamic models. Linear *a priori* dynamic models were obtained from an F-18 HARV nonlinear simulation⁵. The maneuvers were designed specifically to collect flight data with maximum information content for dynamic modeling purposes.

Specific objectives addressed by the maneuvers specified in this document are:

1. Identify closed loop lateral-directional linear dynamic models for validation of the control law design methods implemented by the Actuated Nose Strakes for Enhanced Rolling (ANSER) control law in Strake (S) mode and Strake / Thrust Vectoring (STV) mode.
2. Identify closed loop lateral-directional linear models for comparison and correlation with military specifications for flying qualities of piloted aircraft, pilot comments and handling qualities ratings.
3. Update and verify existing aerodynamic models.

The purpose of this report is to document the specifications for the maneuvers designed to achieve the above objectives.

II. Maneuver Descriptions

There are six (6) optimal square wave input maneuvers described in this report. The maneuvers can be divided into two groups:

1. Three (3) maneuvers for lateral-directional closed loop model identification using the OBES system for the ANSER control law in S mode^{6,7}.
2. Three (3) maneuvers for lateral-directional closed loop model identification using the OBES system for the ANSER control law in STV mode^{6,7}.

Control definitions and sign conventions are given above in the **Nomenclature** section. Detailed descriptions of the maneuvers in each group appear below, with numbering corresponding to that given above.

1. This group of three maneuvers is for identifying closed loop lateral-directional dynamic models and for control law design validation. Initial flight conditions are trim angle of attack 30, 45, and 60 degrees and approximately 25,000 feet altitude, with the ANSER control law in S mode. These maneuvers involve rudder pedal and lateral stick deflection by the On-Board Excitation System (OBES).

Optimal rudder pedal and lateral stick input specifications for $\alpha = 30, 45$ and 60 degrees are given in Tables 1–3, respectively. Each input specification consists of the initial flight condition for the maneuver, followed by a tabulation of the time / amplitude points for the inputs. Figures 1–3 show time histories for the optimal rudder pedal and lateral stick inputs at $\alpha = 30, 45$ and 60 degrees, respectively. Pilot station controls for the initial steady flight condition are defined as zero for the inputs shown in the figures. The inputs included a rate limit of approximately 425 pounds per second on the rudder pedal input and approximately 16 inches per second on the lateral stick input to reduce the effects of control surface rate limiting and to model human pilot capabilities. The stated rate limits are approximate because the physical deflections of the rudder pedal and lateral stick are nonlinear functions of the control system input units which were used in the models for designing the experiment.

Each maneuver in this group is to be flown two (2) times, for a total of six (6) runs. Each run should be preceded by at least two seconds of steady trimmed flight, and followed by at least two seconds of free response before the pilot takes action to control the aircraft. The duration of each maneuver is 20 seconds, and consists of 10 seconds of pure rudder pedal input followed by 10 seconds of pure lateral stick input. Estimated flight time for this set of maneuvers (including repeats) is approximately 15 minutes.

2. This group of three maneuvers is for identifying closed loop lateral-directional dynamic models and for control law design validation. Initial flight conditions are trim angle of attack 30, 45, and 60 degrees and approximately 25,000 feet altitude, with the ANSER control law in STV mode. These maneuvers involve rudder pedal and lateral stick deflection by the On-Board Excitation System (OBES).

Optimal rudder pedal and lateral stick input specifications for $\alpha = 30, 45$ and 60 degrees are given in Tables 4–6, respectively. Each input specification consists of the initial flight condition for the maneuver, followed by a tabulation of the time / amplitude points for the inputs. Figures 4–6 show time histories for the optimal rudder pedal and lateral stick inputs at $\alpha = 30, 45$ and 60 degrees, respectively. Pilot station controls for the initial steady flight condition are defined as zero for the inputs shown in the figures. The inputs included a rate limit of approximately 425 pounds per second on the rudder pedal input and approximately 16 inches per second on the lateral stick input to reduce the effects of control surface rate limiting and to model human pilot capabilities. The stated rate limits are approximate because the physical deflections of the rudder pedal and lateral stick are nonlinear functions of the control system input units which were used in the models for designing the experiment.

Each maneuver in this group is to be flown two (2) times, for a total of six (6) runs. Each run should be preceded by at least two seconds of steady trimmed flight, and followed by at least two seconds of free response before the pilot takes action to control the aircraft. The duration of each maneuver is 20 seconds, and consists of 10 seconds of pure rudder pedal input followed by 10 seconds of pure lateral stick input. Estimated flight time for this set of maneuvers (including repeats) is approximately 15 minutes.

III. Acknowledgments

This research was conducted at the NASA Langley Research Center under NASA contract NAS1-19000.

IV. References

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V. Input Specification Tables

LATERAL CLOSED LOOP OPTIMAL INPUT MANEUVERS

F-18 HARV using the ANSER Control Law in Strake Mode

30 α OPTIMAL RUDDER PEDAL / LATERAL STICK MANEUVER

Initial Conditions

$$\alpha_o = 30^\circ$$

$$V_o = 167 \text{ knots}$$

$$h_o = 25,000 \text{ feet}$$

$$| \text{OBES } \eta_r |_{\max} = 79.034 \text{ pounds}$$

$$| \text{OBES } \eta_a |_{\max} = 2.211 \text{ inches}$$

Table 1

(Figure 1)

OBES rudder pedal	
Time (seconds)	OBES η_r (pounds)
0	0
0.200	-79.034
0.800	-79.034
1.000	0
2.000	0
2.200	-79.034
2.800	-79.034
3.175	79.034
4.000	79.034
4.375	-79.034
5.200	-79.034
5.575	79.034
6.400	79.034
6.600	0
6.800	0
7.000	-79.034
8.000	-79.034
8.375	79.034
9.200	79.034
9.400	0
9.600	0
9.800	-79.034
10.000	-79.034
10.200	0
20.000	0

OBES lateral stick	
Time (seconds)	OBES η_a (inches)
0	0
10.000	0
10.150	2.211
12.000	2.211
12.300	-2.211
13.600	-2.211
13.900	2.211
15.200	2.211
15.350	0
15.600	0
15.750	-2.211
17.600	-2.211
17.900	2.211
19.600	2.211
19.750	0
20.000	0

45 α OPTIMAL RUDDER PEDAL / LATERAL STICK MANEUVER

Initial Conditions

$$\alpha_o = 45^\circ$$

$$V_o = 156 \text{ knots}$$

$$h_o = 25,000 \text{ feet}$$

$$| \text{OBES } \eta_r |_{\max} = 79.034 \text{ pounds}$$

$$| \text{OBES } \eta_a |_{\max} = 2.318 \text{ inches}$$

Table 2

(Figure 2)

OBES rudder pedal	
Time (seconds)	OBES η_r (pounds)
0	0
0.200	79.034
0.800	79.034
1.175	-79.034
1.200	-79.034
1.400	0
1.600	0
1.800	79.034
2.400	79.034
2.775	-79.034
3.600	-79.034
3.975	79.034
4.800	79.034
5.175	-79.034
5.600	-79.034
5.975	79.034
6.400	79.034
6.775	-79.034
7.600	-79.034
7.800	0
8.000	0
8.200	79.034
8.400	79.034
8.600	0
8.800	0
9.000	-79.034
10.000	-79.034
10.200	0
20.000	0

OBES lateral stick	
Time (seconds)	OBES η_a (inches)
0	0
10.0000	0
10.1750	-2.318
11.2000	-2.318
11.5250	2.318
13.2000	2.318
13.5250	-2.318
14.8000	-2.318
15.1250	2.318
18.0000	2.318
18.1750	0
18.4000	0
18.5750	-2.318
19.6000	-2.318
19.7750	0
20.0000	0

60 α OPTIMAL RUDDER PEDAL / LATERAL STICK MANEUVER

Initial Conditions

$$\alpha_o = 60^\circ$$

$$V_o = 163 \text{ knots}$$

$$h_o = 25,000 \text{ feet}$$

$$|\text{OBES } \eta_r|_{\max} = 79.034 \text{ pounds}$$

$$|\text{OBES } \eta_a|_{\max} = 2.421 \text{ inches}$$

Table 3

(Figure 3)

OBES rudder pedal	
Time (seconds)	OBES η_r (pounds)
0	0
0.200	79.034
0.800	79.034
1.000	0
1.200	0
1.400	79.034
1.600	79.034
1.800	0
2.400	0
2.600	79.034
3.200	79.034
3.575	-79.034
4.400	-79.034
4.775	79.034
5.600	79.034
5.800	0
6.000	0
6.200	-79.034
6.800	-79.034
7.000	0
7.200	0
7.400	79.034
8.400	79.034
8.775	-79.034
9.600	-79.034
9.800	0
20.000	0

OBES lateral stick	
Time (seconds)	OBES η_a (inches)
0	0
10.800	0
10.975	-2.421
13.200	-2.421
13.550	2.421
14.800	2.421
15.150	-2.421
16.000	-2.421
16.350	2.421
19.600	2.421
19.775	0
20.000	0

LATERAL CLOSED LOOP OPTIMAL INPUT MANEUVERS

F-18 HARV using the ANSER Control Law in Strake / Thrust Vectoring Mode

30 α OPTIMAL RUDDER PEDAL / LATERAL STICK MANEUVER

Initial Conditions

$$\alpha_o = 30^\circ$$

$$V_o = 167 \text{ knots}$$

$$h_o = 25,000 \text{ feet}$$

$$|\text{OBES } \eta_r|_{\max} = 81.227 \text{ pounds}$$

$$|\text{OBES } \eta_a|_{\max} = 2.211 \text{ inches}$$

Table 4

(Figure 4)

OBES rudder pedal		OBES lateral stick	
Time (seconds)	OBES η_r (pounds)	Time (seconds)	OBES η_a (inches)
0	0	0	0
0.200	-81.227	10.000	0
0.800	-81.227	10.150	2.211
1.200	81.227	10.800	2.211
1.200	81.227	10.950	0
1.400	0	11.200	0
1.600	0	11.350	-2.211
1.800	-81.227	12.800	-2.211
2.000	-81.227	13.100	2.211
2.200	0	14.400	2.211
2.400	0	14.700	-2.211
2.600	-81.227	16.000	-2.211
3.200	-81.227	16.300	2.211
3.600	81.227	17.200	2.211
4.000	81.227	17.500	-2.211
4.400	-81.227	18.400	-2.211
4.800	-81.227	18.700	2.211
5.200	81.227	19.600	2.211
6.000	81.227	19.750	0
6.400	-81.227	20.000	0
7.200	-81.227		
7.600	81.227		
8.800	81.227		
9.200	-81.227		
9.200	-81.227		
9.600	81.227		
10.000	81.227		
10.200	0		
20.000	0		

45 α OPTIMAL RUDDER PEDAL / LATERAL STICK MANEUVER

Initial Conditions

$$\alpha_o = 45^\circ$$

$$V_o = 156 \text{ knots}$$

$$h_o = 25,000 \text{ feet}$$

$$| \text{OBES } \eta_r |_{\max} = 79.034 \text{ pounds}$$

$$| \text{OBES } \eta_a |_{\max} = 2.211 \text{ inches}$$

Table 5

(Figure 5)

OBES rudder pedal	
Time (seconds)	OBES η_r (pounds)
0	0
0.200	-79.034
1.600	-79.034
1.975	79.034
2.000	79.034
2.375	-79.034
3.200	-79.034
3.575	79.034
4.400	79.034
4.775	-79.034
5.600	-79.034
5.975	79.034
7.200	79.034
7.575	-79.034
8.800	-79.034
9.175	79.034
9.600	79.034
9.800	0
20.000	0

OBES lateral stick	
Time (seconds)	OBES η_a (inches)
0	0
10.000	0
10.150	-2.211
11.200	-2.211
11.500	2.211
14.000	2.211
14.300	-2.211
15.200	-2.211
15.500	2.211
16.000	2.211
16.300	-2.211
18.000	-2.211
18.300	2.211
18.800	2.211
19.100	-2.211
19.600	-2.211
19.750	0
20.000	0

60 α OPTIMAL RUDDER PEDAL / LATERAL STICK MANEUVER

Initial Conditions

$$\alpha_o = 60^\circ$$

$$V_o = 163 \text{ knots}$$

$$h_o = 25,000 \text{ feet}$$

$$|\text{OBES } \eta_r|_{\max} = 81.227 \text{ pounds}$$

$$|\text{OBES } \eta_a|_{\max} = 2.421 \text{ inches}$$

Table 6

(Figure 6)

OBES rudder pedal	
Time (seconds)	OBES η_r (pounds)
0	0
0.200	81.227
1.600	81.227
1.800	0
2.400	0
2.600	81.227
2.800	81.227
3.000	0
3.200	0
3.400	-81.227
3.600	-81.227
4.000	81.227
4.400	81.227
4.800	-81.227
6.000	-81.227
6.400	81.227
7.200	81.227
7.600	-81.227
8.000	-81.227
8.200	0
8.400	0
8.600	-81.227
8.800	-81.227
9.200	81.227
10.000	81.227
10.200	0
20.000	0

OBES lateral stick	
Time (seconds)	OBES η_a (inches)
0	0
10.000	0
10.175	2.421
11.200	2.421
11.550	-2.421
13.200	-2.421
13.375	0
13.600	0
13.775	2.421
14.000	2.421
14.350	-2.421
15.200	-2.421
15.550	2.421
16.400	2.421
16.750	-2.421
17.600	-2.421
17.950	2.421
18.800	2.421
19.150	-2.421
19.600	-2.421
19.775	0
20.000	0

VI. Control Time Histories

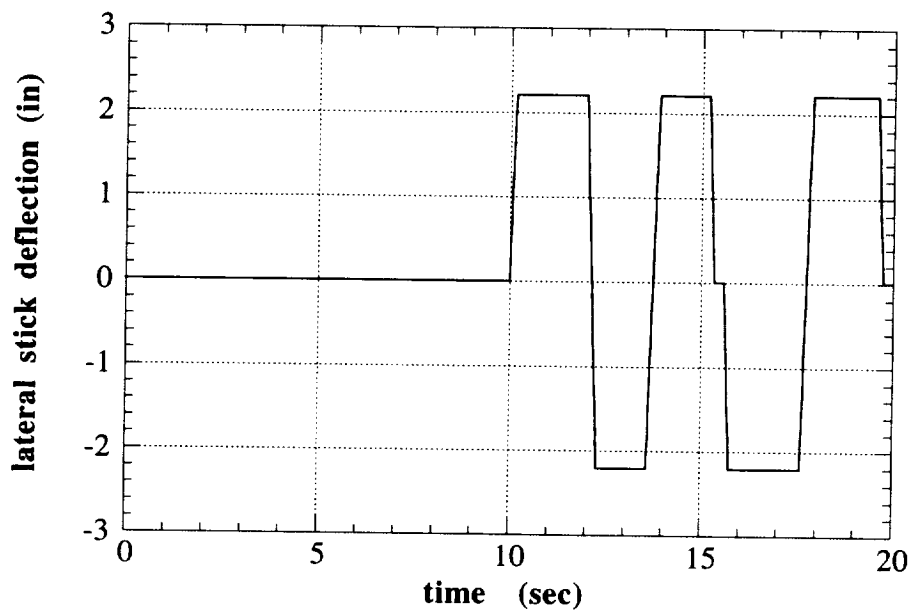
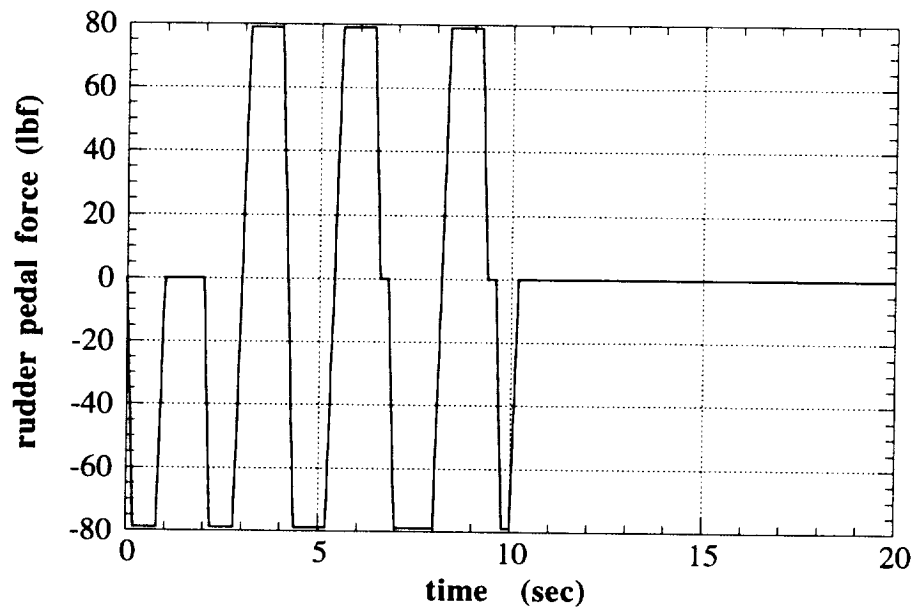


Figure 1 F-18 HARV Optimal Rudder Pedal and Lateral Stick Inputs, Strake Mode, $\alpha = 30$ degrees

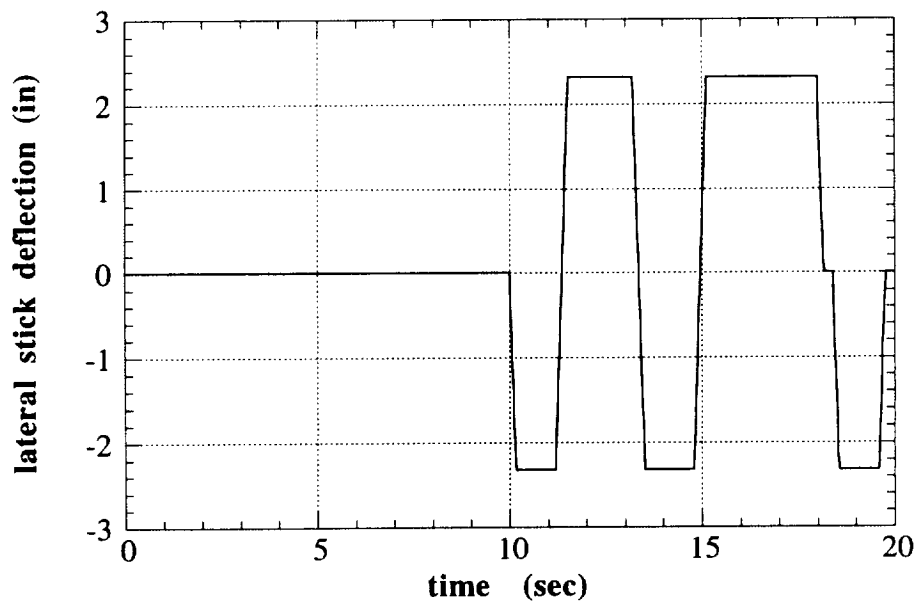
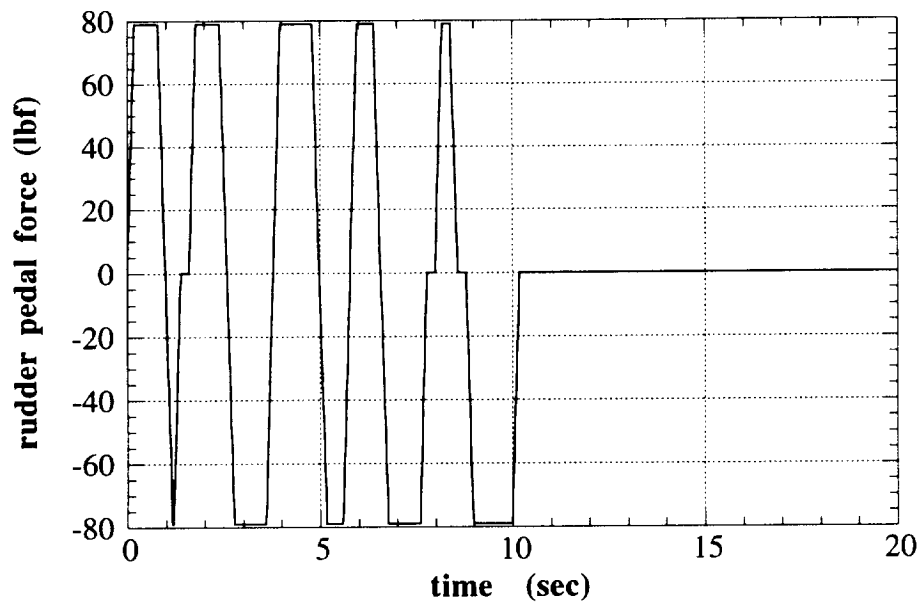


Figure 2 F-18 HARV Optimal Rudder Pedal and Lateral Stick Inputs, Strake Mode, $\alpha = 45$ degrees

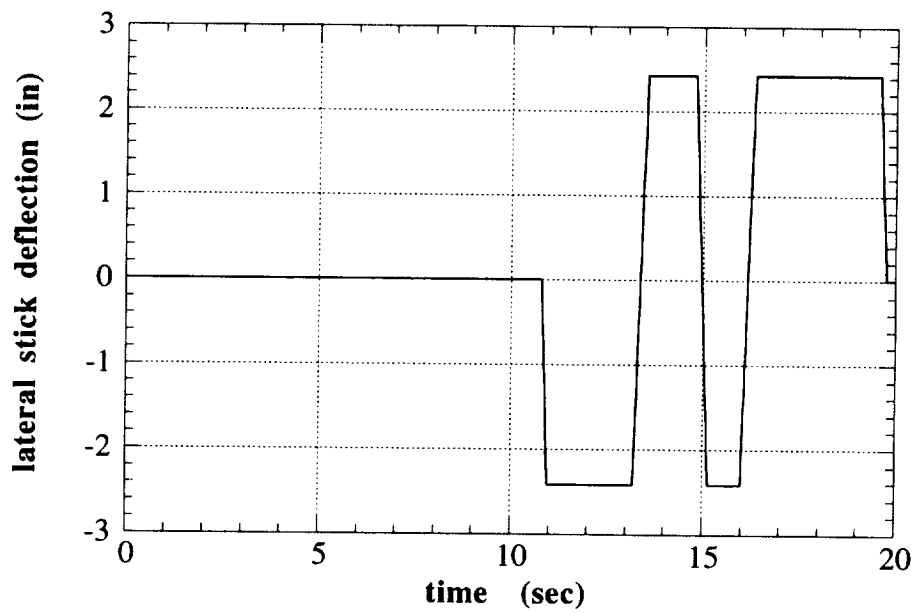
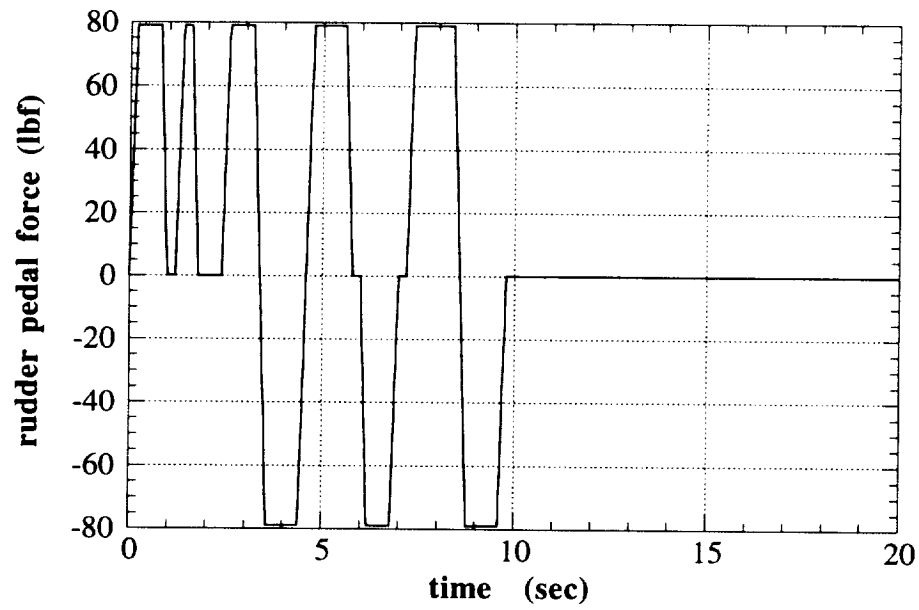


Figure 3 F-18 HARV Optimal Rudder Pedal and Lateral Stick Inputs, Strake Mode, $\alpha = 60$ degrees

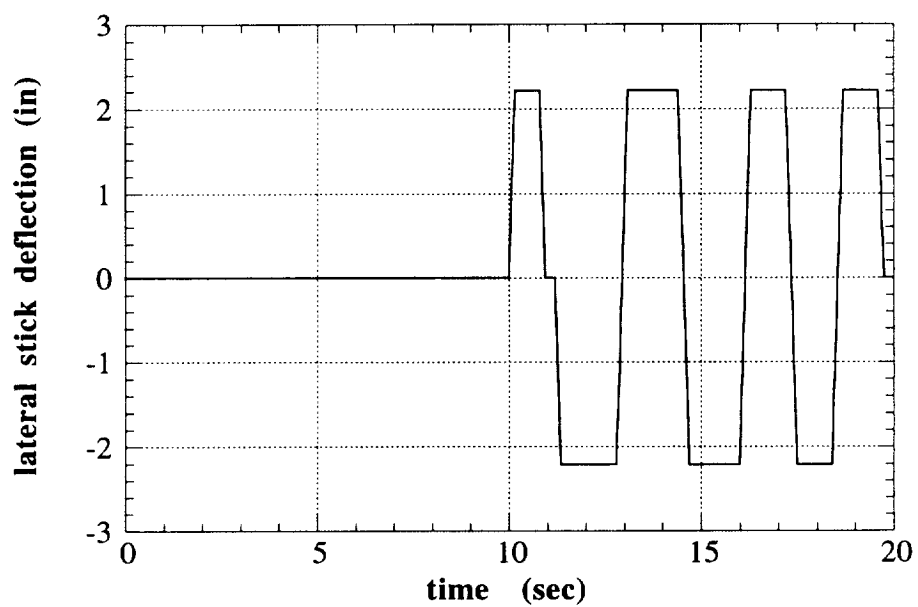
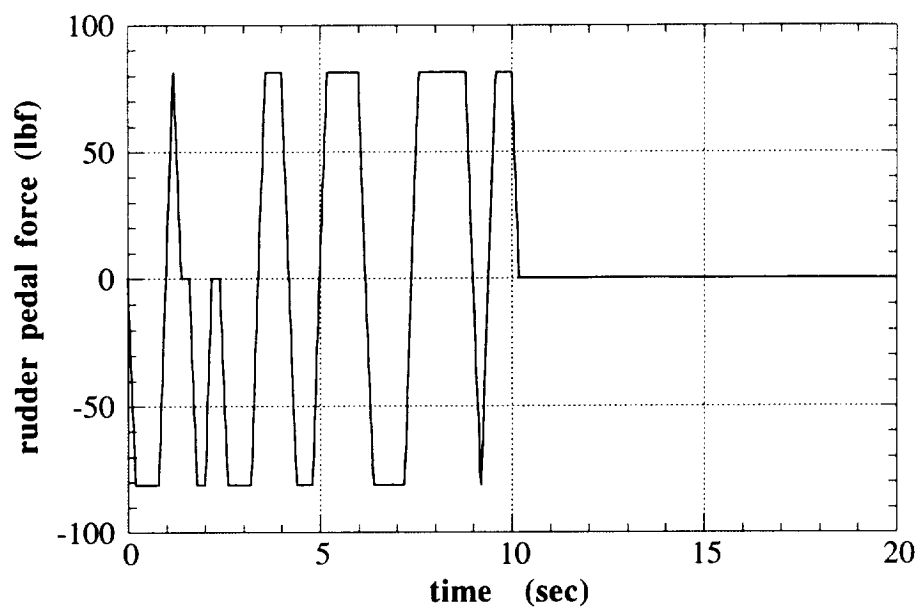


Figure 4 F-18 HARV Optimal Rudder Pedal and Lateral Stick Inputs, Strake / Thrust Vectoring Mode, $\alpha = 30$ degrees

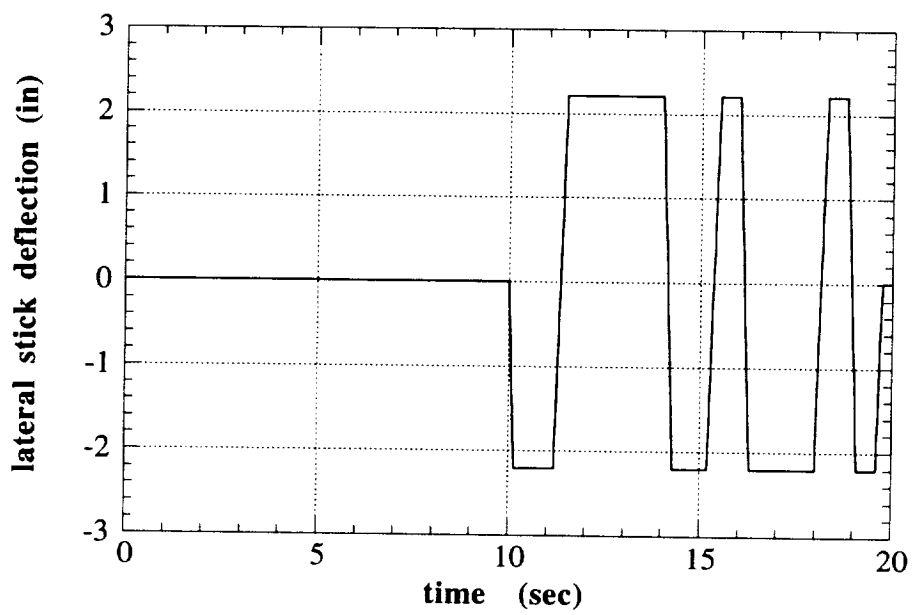
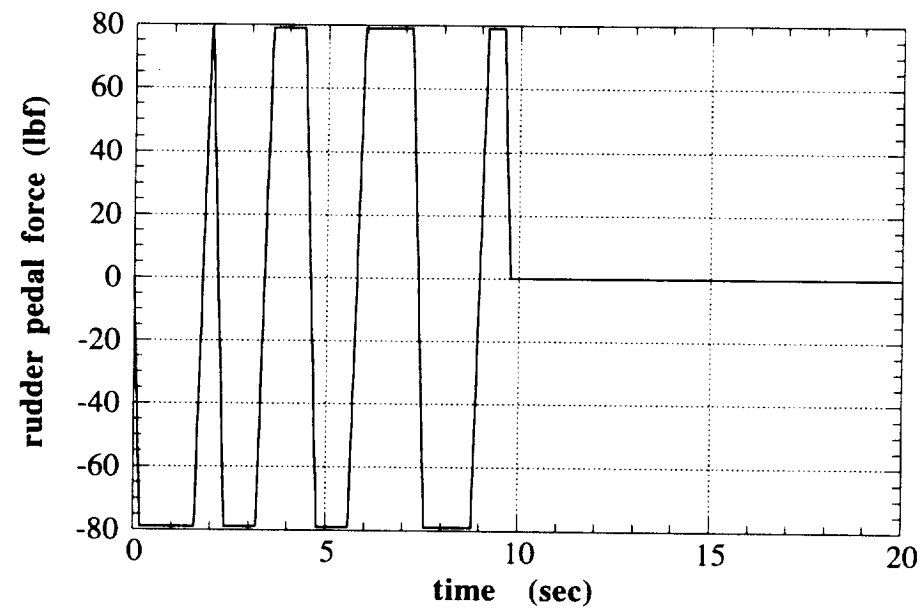


Figure 5 F-18 HARV Optimal Rudder Pedal and Lateral Stick Inputs, Strake / Thrust Vectoring Mode, $\alpha = 45$ degrees

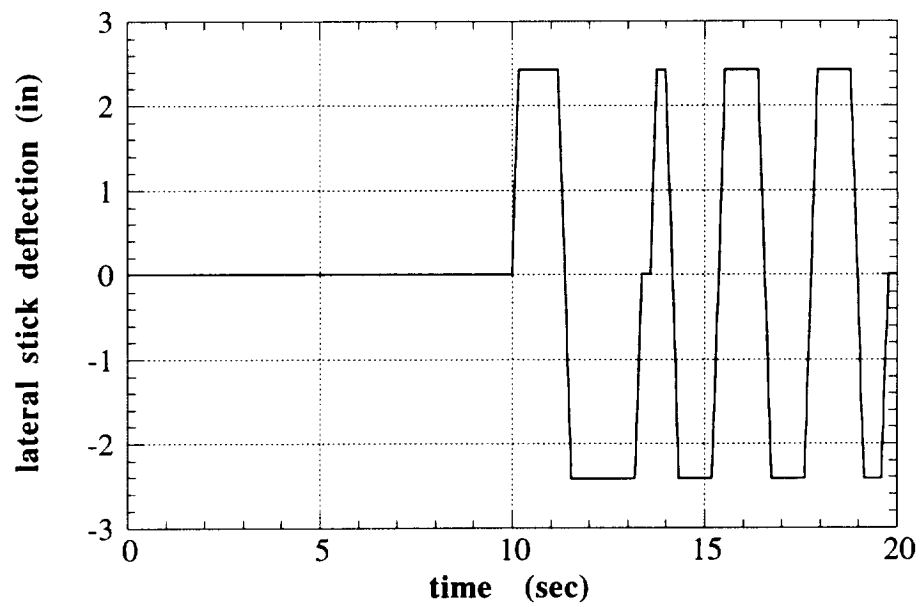
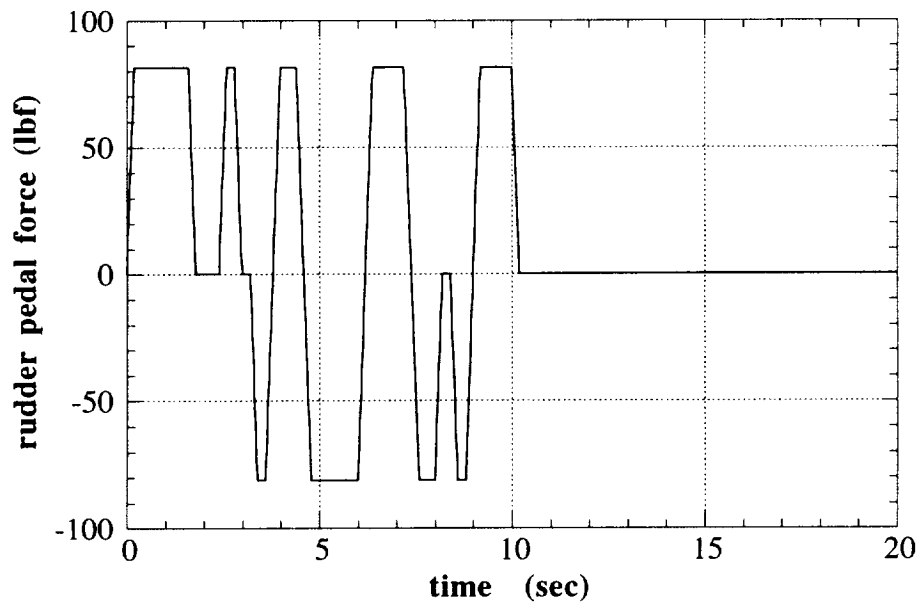


Figure 6 F-18 HARV Optimal Rudder Pedal and Lateral Stick Inputs, Strake / Thrust Vectoring Mode, $\alpha = 60$ degrees

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13. ABSTRACT (Maximum 200 words)

Flight test maneuvers are specified for the F-18 High Alpha Research Vehicle (HARV). The maneuvers were designed for closed loop parameter identification purposes, specifically for lateral linear model parameter estimation at 30, 45, and 60 degrees angle of attack, using the Actuated Nose Strakes for Enhanced Rolling (ANSER) control law in Strake (S) model and Strake/Thrust Vectoring (STV) mode. Each maneuver is to be realized by applying square wave inputs to specific pilot station controls using the On-Board Excitation System (OBES). Maneuver descriptions and complete specification of the time/amplitude points defining each input are included, along with plots of the input time histories.

14. SUBJECT TERMS

Flight test maneuvers, parameter identification, optimal input design, closed loop modeling, forebody strakes, F-18 HARV

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